Stellar Clusters & Associations: A RIA Workshop on Gaia
Granada, 23rd - 27th May 2011

Using open clusters to study mixing in low- and intermediate-mass stars

Rodolfo Smiljanic

European Southern Observatory, Garching bei München, Germany

Abstract

In many evolutionary stages, low- and intermediate-mass stars show signs of mixing of the surface material with material from the interior. To account for all the details revealed by the observations it is necessary to include non-standard physical processes in the models (e.g. atomic diffusion and rotation-induced mixing). The study of mixing in stars of different masses, ages, and chemical composition helps to identify and constrain these processes. In this sense, stars in open clusters are the ideal targets. All stars in one given cluster have the same age and chemical composition, and their masses can be well estimated. By studying many clusters, one can separate and trace the effects of these different parameters.

1 The early main sequence

Lithium and beryllium burn at low but different temperatures (2.5×10^6 K and 3.5×10^6 K, respectively). Their abundances can be used to study mixing in the outer layers of stars (see e.g. Smiljanic et al. 2010, and references therein). Observations of stars in young clusters (from $\sim$ 10 to 100 Myr) have shown that pre-main sequence (PMS) models predict too much Li depletion. In addition, there is a significant spread in Li abundances among late-G and K dwarfs which is connected to rotation, i.e. fast-rotating stars have higher Li abundances than slow-rotating ones (see e.g. Balachandran et al. 2011, and references therein).

Beryllium has been studied in far fewer stars than Li has. In Smiljanic, Randich & Pasquini (2011, submitted) we derived Be abundances in ten G- and K-type main-sequence stars of the open clusters IC 2391 and IC 2602 ($\sim$ 50 Myr). As these stars have just arrived on the main sequence, any change in Li and Be should have taken place during the PMS.

All stars have, within the uncertainties, the same Be abundances even though their Li abundances differ by almost one order of magnitude. This confirms what is expected by the models; Be abundances are not affected by mixing during the PMS in stars between $0.80 \leq M/M_\odot \leq 1.20$. Comparing our Be abundances with those of other young clusters from the literature, we confirm that Be depletion in stars cooler than $\sim$ 5600 K increases with age.

The depletion is stronger for smaller masses. As stars with ages of 50 and 150 Myr do not show Be depletion, we conclude that the depletion in older stars happens during the main sequence, in agreement with Randich et al. (2007).

2 The Li-Be dip

The so-called Li-dip is a strong decrease in the Li abundance seen in main-sequence stars in a small temperature range around 6700 K. It was first found by Boesgaard & Tripicco (1986) in the Hyades. Be was also found to be depleted in these stars (see e.g. Smiljanic et al. 2010, and references therein).

In Smiljanic et al. (2010) we derived Be abundances along the whole evolutionary sequence of the cluster IC 4651 (~ 1.7 Gyr). A well defined LiBe-dip was found (Li abundances from Pasquini et al. 2004). The hydrodynamical models of Charbonnel & Lagarde (2010) reproduce well the observed behavior of Li and Be over the whole temperature range. The hot side of the dip requires models with atomic diffusion, and transport of angular momentum and chemicals by meridional circulation and shear turbulence. In the cool side of the dip, the models also take into account extraction of angular momentum by internal gravity waves.

3 The red giant branch

Abundances of C, N, O, and the $^{12}C/^{13}C$ in low-mass giants, before the bump were found to be in good agreement with theoretical predictions. However, after the bump an additional mixing event takes place resulting in further abundance changes (see e.g. Smiljanic et al. 2009, and references therein).

In Smiljanic et al. (2009) we derived C, N, O, Na, and $^{12}C/^{13}C$ in 31 giants, with $1.7 \leq M/M_{\odot} \leq 3.1$, of 10 open clusters. We found that the well-known trend of decreasing carbon ratio with decreasing mass is not so well defined, but shows a significant scatter. The decrease of $^{12}C/^{13}C$ can be explained by the action of thermohaline mixing while the scatter might be partially explained by a dispersion in the initial rotation velocities of the stars (Charbonnel & Lagarde 2010). The lowest values found are however difficult to explain. New homogeneous analyses are needed to confirm and better constrain these results.

References

Balachandran, S. C., Mallik, S. V., & Lambert, D. L. 2011, MNRAS, 410, 2526

Boesgaard, A. M. & Tripicco, M. J. 1986, ApJL, 302, L49

Charbonnel, C. & Lagarde, N. 2010, A&A, 522, A10+

Pasquini, L., Randich, S., Zoccali, M., et al. 2004, A&A, 424, 951

Randich, S., Primas, F., Pasquini, L., Sestito, P., & Pallavicini, R. 2007, A&A, 469, 163

Smiljanic, R., Gauderon, R., North, P., et al. 2009, A&A, 502, 267

Smiljanic, R., Pasquini, L., Charbonnel, C., & Lagarde, N. 2010, A&A, 510, A50